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EFFECT OF NITROGEN AND SULFUR ON THE QUALITY OF THE COTTON FIBER UNDER MEDITERRANEAN CONDITIONS

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Micronaire

Nitrogen-Sulfur interaction

ABSTRACT

Agronomic practices significantly influence the productivity and quality of cotton plant. Present study was undertaken to evaluate the effect of nitrogen and sulfur fertilizer application on the fiber quality of cotton, during the year 2011/2012 and 2012/2013 under Mediterranean environmental conditions. All the treatments were laid in randomized complete block design in factorial arrangement each treatment were replicated thrice. Five rates of nitrogen (0, 60, 120, 180 and 240 kg ha^{-1}) and five rates of sulfur (0, 15, 30, 45 and 60 kg ha^{-1}) were involved in the experiments. Results of study indicated that increases in the rate of sulfur have negative impact on the quality of the cotton fiber and the highest rate of sulfur fertilizer gave the lowest fiber length compared with the other sulfur rates. On the other hand, the lowest uniformity ratio was observed by applications of sulfur at 30, 45 or 60 kg ha^{-1}. It was observed that application of sulfur had no significant effect on micronaire and fiber strength. Further, application of 60 to 120 kg N ha^{-1}have positive effect on the fiber length and caused 2.7 to 3.4% improvement in fiber lengths in 2012 compared to the treatment without N, while applications of nitrogen at 180 and 240 kg ha^{-1} did not provide an additional increase in fiber lengths. Further, it was reported that application of N significantly improved fiber strength, but these differences were not statistically different from the

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lowest rate of application and the control treatments in both years and averaged across years. On the other hand, the highest values for uniformity ratio was recorded by using 60 to 180 kg N ha^{-1} in 2011.On the basis of these observations, it can be recommend that the use of 120 to 180 kg ha^{-1} N in terms of fiber length and fiber strength and 30 to 45 kg ha^{-1} S, particularly in terms of fiber length and gin turnout in other areas with similar ecologies. Interestingly, the combination of 60 kg ha^{-1} N and 15 kg ha^{-1} S were the optimal and could be the most beneficial application for achieving the maximum fiber strength in similar ecologies.

1 Introduction

Inadequate and unbalanced nutrient supply can affect the yield and quality of the cotton. So, proper nutrient management is the primary needs of the sustainable crop production, higher yield and improved fiber quality. This quality of cotton is gradually changing with introducing new and improved varieties for cultivation. Further, these introduced new high yielding varieties change the concept of nutrient requirement of cotton (Khader & Prakash, 2007; Rochester et al., 2012). Fiber properties can be a strong yield components and the quality of cotton lint is an important consideration since it is a major determinant of its price in the international markets (LaFerney, 1969; MacDonald et al., 2010).

It stands to reason that if a plant has more, longer or heavier fibers then it have a higher yield. The availability of fertilizers are the major constraints in cotton production in most of cotton producing area (Morrow & Krieg, 1990). Proper fertilization practices in cotton crop ensure improved economics of production, efficiency of nutrient use, and environmental protection. Most of the researcher worked on the application of primary fertilizers N, P & K and reported a pronounced effect of these fertilizers on the cotton production (Mullins & Burmester, 1990; Nawaz et al., 1996; Gill et al., 2000; Seagull et al., 2000; Reddy et al., 2004). According to Hutmacher et al. (2004) nitrogen is a limiting factor in both dryland and irrigated cotton production systems. Further, Gerik et al. (1994) reported that cotton deficiency caused reduction in the vegetative and reproductive growth in cotton crop. Moreover, Tewolde & Fernandez, (1997) and Howard et al. (2001) reported the significant effect of nitrogen fertilizers on the reproductive development especially at bloom or at early boll fill. Another important aspect of N nutrition is its effect on fiber quality as well as on yield.

However, studies show different results. Boquet (2005) reported that fiber quality characteristics did not improve by N rates unless severe N deficiency conditions occur. Varying rates of the N fertilizer did not affect fiber length, strength and micronaire (Rashidi & Gholami, 2011; Saleem et al., 2010; Seilsepour & Rashidi, 2011). On the contrary, there are many reports which are showing the significant effects of N fertilizer applications on cotton fiber quality (Fritschi et al., 2003; Read et al., 2006). Rochester et al. (2001) indicated that fiber length and fiber strength generally increased with an increase in N application rate, whereas a decline in micronaire was detected with increasing rates of applied N. Similarly, Bauer & Roof (2004) observed lower fiber length and strength when no nitrogen was applied. Further, Tewolde & Fernandez (2003) indicated that fiber length and micronaire was significantly affected with increasing rate of applied nitrogen. Girma et al. (2007) reported significantly reduced fiber length, strength and micronaire with application of N rates greater than 90 kg ha^{-1}. Ali & Hameed (2011) also reported increased fiber length with increase in N fertilizer rate. Like nitrogen, potassium and phosphorus fertilizers also affect the vegetative and reproductive quality of the cotton crop (Nawaz et al., 1996; Gill et al., 2000). Although most of the researches are based on N, P & K but very limited information are available regarding the use of sulfur and its effect on the quality and yield of the cotton crop. Because both nitrogen and sulfur is required to promote the components of seeds and lint, it is essential to keep these two companion nutrients in balance with each other and to meet adequately balanced supply of both nutrients to plant. Sulfur (S) deficiencies in crops have increasingly occurred because of the less concern of the researchers toward the sulfur.

Excess use of sulfur free fertilizers, greater removal of sulfur from soil by crops, less sulfur deposition to soil from the atmosphere and declined use of sulfur containing pesticides are the some causes of less availability of the fertilizer of cotton crop (Scherer, 2001). Tucker (1999) reported that addition of sulfur into the soil not only increases yield and protein quality of forage and grain crops but also increases the production and quality of fiber crops. Very little knowledge has been available regarding the influence of sulfur fertilizer on cotton. The application of 30 kg S ha^{-1} resulted in increased span length and uniformity ratio (Sharma et al., 2000). Quality of lint (fiber length, uniformity, fiber strength) increased with increase in gypsum level from 0 to 200 kg ha^{-1}, compared to the untreated control (Makhdum et al., 2001). Cotton literature contains little information on fiber quality response to sulfur fertilization. Further, information regarding the interaction of S and N on fiber quality of high-yielding cotton cultivars is also available in scarcity. So, the objectives of the current research were to determine the optimum rate of N and S applications to cotton and to evaluate the effect of N and S nutrition and their interactions on fiber properties of cotton under Mediterranean conditions.

2 Materials and Methods

2.1 Experimental site and Initial Soil Characteristics

The experiments were conducted in clay soil in the Mediterranean type climate at the experimental area of Cukurova University, Adana, Turkey (37°N 35°E and altitude 161 m), during 2011/2012 and 2012/ 2013. The soil of the experimental plots is classified as slightly alkaline and had low levels of nitrogen N (37 ppm), organic matter (0.67%), sulfate- sulfur (10 ppm) and the content of pH was 7.5 (Gormus, 2015).

2.2 Experimental materials, Design and agronomic practices

Randomized complete block design in factorial arrangement with three replicates was used in the experiment. Treatments comprised five levels of Nitrogen (0, 60, 120, 180, and 240 kg ha^{-1}) as ammonium nitrate (33.5% N), corresponding to N0, N60, N120, N180 and N240 kg N $ha^{-1}$and five S levels (0, 15, 30, 45, and 60 kg S ha^{-1}) with gypsum source (18% S), corresponding to S0, S15, S30, S45 and S60 kg S $ha^{-1}$for this study. Treatment N0 and S0 represent to the fertilizers control. Nitrogen was provided in broadcast as a top dressing in three doses among these first one third applied at the time of planting, while the second one third was applied at first blooming and the remaining one third at peak bloom stages. Whole amount of sulfur fertilizer was broadcasted and incorporated in the soil at the time of final land preparation. The crop also received a basal application of 70 kg P ha^{-1} as triple superphosphate at the time of final land preparation. Cotton, variety SG 125, was planted on April 25, 2011 and on May 5, 2012. Plots consisted of six rows, 10m long with 0.70 m row spacing, and a buffer zone of 1.4 m unfertilized area between each plot. All plots were maintained throughout the season with standard herbicide, insecticide, and irrigation production practices as recommended for the region.

2.3 Measurements and Instruments

Defoliation was performed when 60 to 70 percent of the bolls were open. All plots were hand-harvested by picking seed cotton from the center four rows of each plot on October and the seed cotton was weighed. Subsamples were collected from each plot to determine gin turnout and fiber characteristics. Seed cotton samples were ginned in small roller gin and lint samples were sent to Commodity exchange in Adana, Turkey for HVI (high volume instruments) fiber measurements. The fiber quality parameters analyzed were fiber length, uniformity ratio, micronaire and strength.

2.4 Statistical analysis

All collected data were subjected to analysis of variance according to Gomez & Gomez (1984). Analysis of variance was performed using the MSTATC statistical package and the grouping of means was determined using the LSD test at the 5% probability level.

3 Results and Discussion

In this research, efforts were made to improve quality traits of cotton lint through nitrogen and sulfur managing in Mediterranean ecologies.

3.1 Gin turnout

Based on the results of this study, it was observed some variation in the gin turnout but no significant interaction was reported among the combination of year X N-rate X S-rate for any studied traits. The interactions between N and S-rate have significant effect on the fiber length and fiber strength. Further, main effects of individual applications of N and S were significant for gin turnout, fiber length and uniformity ratio. Interaction between Year X N-rate was also reported significant for gin turnout and uniformity ratio. While the interaction between the Year X S-rate was not significant results for any traits studied (Table 1). In 2011, application of N (60, 120, 180, and 240 kg ha^{-1}) at all four rates increased gin turnout compared with the control treatment. Maximum gin turnout was achieved at 120 kg N ha^{-1} treatment. While in 2012, highest gin turnout was reported from the plant treated by 60 or 120 kg N $ha^{-1}$and these two treatments were almost at par to each other (Table 2).

Table 1 Mean squares from analysis of variance ofgin turnout and fiber properties.

Source	df	Gin turnout	Micro naire	Fiber length	Unif. ratio	Fiber strength
Replicate	2	3.023	0.708	3.24	12.00	32.4
Year (Yr)	1	67.872**	0.000	2.52	0.00	0.88
Nitrogen(N)	4	100.22**	0.029	3.6**	33.1**	20.0**
Yr x N	4	16.45**	0.012	0.02	18.9**	1.50
Sulfur (S)	4	4.218**	0.130	2.36*	6.8**	3.16
Yr x S	4	1.032	0.054	0.04	0.76	1.18
N x S	16	1.821	0.133	1.8**	1.86	9.43**
Yr x N x S	16	1.526	0.033	0.03	0.88	0.86
Error	98	1.006	0.099	0.68	1.68	2.18

Note: * and ** are significant at 0.05 and 0.01 probability levels, respectively

Table 2 Effect of N and S rates on gin turnout and micronaire.

	Gin turnout (%)			Micronaire		
N rate (kg ha^{-1})	**2011**	**2012**	Mean	**2011**	**2012**	Mean
0	37.6^{e}	37.6^{c}	37.6^{d}	5.4	5.4	5.4
60	40.8^{c}	40.7^{a}	40.8^{b}	5.5	5.5	5.5
120	43.4^{a}	40.6^{ab}	42.0^{a}	5.4	5.5	5.5
180	42.8^{b}	39.7^{b}	41.3^{b}	5.5	5.5	5.5
240	39.2^{d}	38.4^{c}	38.8^{c}	5.5	5.5	5.5
LSD$_{(0.05)}$	0.52	0.89	0.66	ns	ns	ns
S rate (kg ha^{-1})						
0	40.5	38.7^{c}	39.6^{b}	5.6	5.6	5.6
15	40.7	39.3^{ac}	40.0^{ab}	5.5	5.5	5.5
30	40.9	40.0^{a}	40.5^{a}	5.5	5.4	5.4
45	41.0	39.9^{ab}	40.5^{a}	5.4	5.5	5.4
60	40.7	39.1^{bc}	39.9^{b}	5.5	5.6	5.5
LSD$_{(0.05)}$	ns	0.89	0.48	ns	ns	ns

Means followed by the same letter are not significantly different at P=0.05 level

Averaged across years, 120 kg ha^{-1}N application significantly increased gin turnout throughout the year while the higher rate than this caused significantly decrease in gin turnout. Application of sulfur fertilizers at all rate did not show any effect on the gin turnout in 2011, however, in 2012 some improvement in gin turnout was reported on the application of 30 to 45 kg ha^{-1}. Averaged across years, maximum response of gin turnout to S applications occurred with application of 15 to 45 kg ha^{-1}. The increase in gin turnout might be due to the effect of N accumulation of photosynthates, which would directly influence boll weight and seed cotton weight per boll and increase in gin turnout. Similar type of results was reported by Phipps et al. (1996), these researchers suggested that higher concentration of nitrogen fertilizers minimum or non-significantly effect on plant growth. Similarly Hussain et al. (2000) reported that gin turnout did not respond to N fertilization.

3.2 Micronaire

Both N and S treatments did not have any significant effects on micronaire quality for both the years and averaged across years (Table 1, 2). In general, N application had negative effects on micronaire. Tewolde & Fernandez (2003) reported that the increase in nitrogen rate have small but highly significant linear improvement in micronaire quality. Bauer &Roof (2004) found that micronaire was affected by N fertilizer rate where cotton with control treatments produced lower micronaire than the cotton grown at 78.4-112.0 kg N ha^{-1}.

Table 3 Effect of N and S rates on fiber length, uniformity ratio and fiber strength.

	Fiber length (mm)			Uniformity ratio (%)			Fiber strength (g tex^{-1})		
N rate (kg ha^{-1})	**2011**	**2012**	Mean	**2011**	**2012**	**Mean**	**2011**	**2012**	Mean
0	29.6	29.3^{b}	29.5^{b}	80.9^{d}	83.7	82.3^{d}	29.9^{b}	30.2^{b}	30.1^{b}
60	30.2	30.1^{a}	30.2^{a}	85.2^{ab}	84.1	84.7^{ab}	30.5^{b}	30.8^{b}	30.1^{b}
120	30.6	30.3^{a}	30.4^{a}	83.8^{c}	83.4	83.6^{c}	31.7^{a}	31.7^{a}	31.7^{a}
180	30.2	29.9^{ab}	30.1^{a}	85.5^{a}	84.5	85.0^{a}	32.3^{a}	31.7^{a}	32.0^{a}
240	30.1	29.8^{ab}	30.0^{ab}	84.3^{bc}	84.1	84.2^{bc}	31.9^{a}	31.4^{a}	31.7^{a}
LSD$_{(0.05)}$	ns	0.61	0.54	0.97	ns	0.68	1.15	1.03	0.84
S rate (kg ha^{-1})									
0	30.4	30.1	30.3^{a}	84.7	84.5	84.6^{a}	30.8	31.4	31.1
15	30.2	29.9	30.1^{a}	84.4	84.2	84.3^{ab}	31.9	31.6	31.7
30	30.3	30.0	30.2^{a}	83.9	83.8	83.9^{bc}	31.3	30.9	31.2
45	30.2	29.9	30.1^{a}	83.0	83.6	83.3^{c}	31.5	31.2	31.3
60	29.6	29.5	29.6^{b}	83.9	83.8	83.9^{bc}	31.0	30.8	30.9
LSD$_{(0.05)}$	ns	ns	0.40	ns	ns	0.67	ns	ns	ns

Means followed by the same letter are not significantly different at P=0.05 level

Table 4 Effects of interaction between N rate (kgha^{-1}) and S rate (kgha^{-1}) on fiber length and fiber strength (averaged over two years).

		N0	N60	N120	N180	N240
				Fiber length (mm)		
S0		29.8	30.0	30.6	31.2	29.8
S15		29.3	30.0	30.0	30.0	31.0
S30		29.6	31.0	30.5	29.3	30.6
S45		29.4	29.6	31.0	30.3	29.9
S60		29.4	29.3	30.2	29.4	29.5
$LSD_{0.05}$	**1.54**					
CV (%)	**2.76**					
				Fiber strength (gtex^{-1})		
S0		30.0	30.1	31.5	33.1	30.8
S15		28.5	33.9	30.6	32.9	32.9
S30		30.7	30.3	31.3	31.3	32.2
S45		30.5	30.0	33.4	31.4	31.4
S60		30.7	29.2	32.0	31.3	31.3
$LSD_{0.05}$	**3.52**					
CV (%)	**4.73**					

3.3 Fiber lengths

In 2011, neither N nor S treatments have significant effect on the fiber lengths (Table 3). In year 2012, application of 60 to 120 kg N ha^{-1} increased fiber lengths by 2.7 to 3.4% compared to the control (without N) while the applications of nitrogen fertilizer at 180 and 240 kg ha^{-1} did not provide an additional increase in fiber lengths. In this manner, findings of Tewolde & Fernandez (2003) are contradictory to the findings of this study; these researchers reported that nitrogen had a significant quadratic effect on fiber length, while the results of the present study are similar to the findings of Gormus et al. (2016). The significant N X S interaction revealed that mean maximum fiber length (31.2 mm) was recorded in treatment containing 180 kg N ha^{-1} and 0 kg S ha^{-1} treatment that was followed by (45 kg S ha^{-1} + 120 kg N ha^{-1}) with fiber length (31.0 mm) (Table 4). It was observed that S treatments did not have any significant effects on fiber length for both the years. Averaged across years, application of nitrogen at all four rates improved fiber length compared with control treatment. By contrast to N applications, fiber length decreased from 30.3 mm with no S to 29.6 mm with 60 kg S ha^{-1}. The shortest fibers were attained when S was applied at rate of 60 kg ha^{-1} (Table 3).

3.4 Uniformity ratio

N application significantly affected uniformity ratio in 2011, but it was not reported for the year 2012.The optimum responses of uniformity ratio to N fertilizer was achieved by adding 60 to180 N kg ha^{-1}. Nitrogen at 120 and 240 kg ha^{-1} resulted in similar uniformity ratios in 2011. Averaged across years, the maximum response of mean uniformity ratio for both years to S application occurred in the control treatment which was followed by S application of 15 kg ha^{-1}. Uniformity ratio tended to decrease by the use of higher S rates (30, 45, and 60 kg ha^{-1} S), but the effects were small on quality (Table 3). Yin et al (2011) reported that application of 22 or 34 kg S ha^{-1} increased micronaire by 4 to 5% compared to the treatments without S, although other fiber quality characteristics including length, uniformity and strength were found not to be affected by S applications.

3.5 Fiber strength

Application of N significantly increased fiber strength, although differences were not statistically significant between the lowest rate and the control treatments in both years and averaged across years. Fiber strength did not change with S rate in both years. N application gave the greatest increase in fiber strength when N was applied at rates of 120, 180 or 240 kg ha^{-1}, while applying N at rate of 60 kg ha^{-1} gave the same mean strength values as the control treatment (Table3).The significant N X S interaction revealed that maximum fiber strength (33.9 gtex^{-1}) was observed with the treatment consisting of 15 kg S ha^{-1} and 60 kg N ha^{-1}and it was followed by the combined application of 45 kg S ha^{-1}+ 120 kg N ha^{-1}) with fiber strength (33.4 g tex^{-1}) (Table.4). Either the addition of more S, i.e. 45 instead of 30 kg S ha^{-1} along with the same rate of N, i.e. 60 kg N ha^{-1}, or a reduction in the rate of N, i.e. from 180 to 120 kg N ha^{-1} with the same amount of S, i.e. 30 kg S ha^{-1} resulted in decreased the fiber strength. Plots that have not received S (control) but have 120 kg N ha^{-1} produced an increase in fiber strength by 1.5 g tex^{-1}, when S was added at the rate of 15 kg ha^{-1} the decrease in fiber strength with 180 kg ha^{-1} over lowest N rate was 1.0 g tex^{-1} (Table 4).

In a longer period and more tempered cellulose accumulation process benefited to higher strength fiber formation. According to Bradow & Davidonis (2000) during the fiber development process, the stage at which the cotton plant is under N stress is crucial for fiber quality. The reduction in fiber length and strength (Read et al., 2006) and improved micronaire value (Reddy et al., 2004) were reported due to the nitrogen deficiencies. Under both N deficiency and excess N conditions, nitrogen accumulation is reduced and this results in decreased fiber length. N and S treatments did not result in significant differences in micronaire. Findings of present study confirm that nitrogen is excess than certain rate does not necessarily result in the longest fibers. Just as in yield, there seems to be an optimum nitrogen rate that results in the longest fibers. In the present study, the nitrogen deficient plants (0 kg N ha^{-1}) produced the weakest fibers but this strength value was not significantly different from the value of 60 kg N ha^{-1} treatment.

The quality of lint was maximized with the increase in gypsum level from 0 to 200 kg ha^{-1}, fiber length, uniformity ratio and fiber strength over control (Makhdum et al., 2001). Mangal (2000) reported that application of sulfur significantly influenced the fiber strength. Sulfur applications produced 4 to 5% increases in micronaire compared to zero S treatment; however, length, uniformity and strength were not significantly affected by S applications (Stewart et al., 2011). Yin et al. (2011) observed 4 to 5% increases in micronaire and no differences in fiber length, uniformity ratio and strength with S applications compared to zero S treatment.

Conclusions

Under the conditions of this study, the results from the two years support evidence that N deficiency decreased fiber length, strength and uniformity ratio. Application of nitrogen gave the higher fiber lengths compared with the untreated control treatment, while applying 180 kg N ha^{-1} produced more uniform fibers. Trends toward higher strength values were observed with the higher rates of N fertilizer applied. The highest rate of S fertilizer gave the lowest fiber length compared with the other sulfur and the untreated control treatments. On the other hand, the lowest uniformity ratio values were obtained when plant was treated with S at 30, 45 or 60 kg ha^{-1}. Micronaire revealed no significant differences due to treatment effects. On the basis of these observations, we recommend use of 120 to 180 kg ha^{-1} N in terms of fiber length and fiber strength and 30 to 45 kg ha^{-1} S, particularly in terms of fiber length and gin turnout in other areas with similar ecologies. Interestingly, the combination of 60 kg ha^{-1} N and 15 kg ha^{-1} S were the optimal treatment and could be the most beneficial application for achieving the maximum fiber strength in similar ecologies.

Conflict of interest

Authors would hereby like to declare that there is no conflict of interests that could possibly arise.

References

Ali H, Hameed RA (2011) Growth, yield and yield components of American cotton (Gossypium hirsutum L.) as affected by cultivars and nitrogen fertilizer. International Journal of Scientific & Engineering Research 2:1-13.

Bauer PJ, Roof ME (2004) Nitrogen, aldicarb, and cover crop effects on cotton yield and fiber properties. Agronomy Journal 96: 369-376. doi:10.2134/agronj2004.3690.

Boquet DJ (2005) Cotton in ultra-narrow row spacing: plant density and nitrogen fertilizer rates. Agronomy Journal 97: 279-287. doi:10.2134/agronj2005.0279.

Bradow JM , Davidonis GH (2000) Quantitation of fiber quality and the cotton production-processing interface: a physiologist's perspective. Journal of Cotton Science 4: 34-64.

Fritschi FB, Roberts BA, Travis RL, Rains DW, Hutmacher RB (2003) Response of irrigated Acala and Pima cotton to nitrogen fertilization. Agronomy Journal 95: 133-146. doi:10.2134/agronj2003.1330.

Gerik TJ, Jackson BS, Stockle CO, Rosenthal WD (1994) Plant nitrogen status and boll load of cotton. Agronomy Journal 86:514-518. doi:10.2134/agronj1994.00021962008600030011x

Gill KH, Sherazi SJA, Iqbal J, Ramzan M, Shaheen MH, Ali ZS (2000) Soil fertility investigations on farmers fields in Punjab", Soil Fertility Research Institute, Department of Agriculture, Government of Punjab, Lahore, Pakistan, pp. 133-135.

Girma K, Teal RK, Freeman KW, Boman RK, Raun WR (2007) Cotton lint yield and quality as affected by applications of N, P, and K fertilizers. Journal of Cotton Science 11, 12-19.

Gomez K, Gomez A (1984) Statistical Procedures of Agricultural Research. John Wiley and Sons.Inc., New York,U.S.A.

Gormus O (2015) Evaluation of cotton growth and yield response to nitrogen and sulfur fertilization. SDU Journal of the Faculty of Agriculture 10 :1-7.

Gormus O, EL Sabagh A, Islam MS (2016) Optimizing yield and fiber quality of cotton under mediterranean environment: managing nitrogen and potassium nutrition. Journal of Experimental Biology and Agricultural Sciences 4 (Suppl. V) : 572-580. doi: 10.18006/2016.4(5S).572.580

Howard DD, Gwathmey CO, Essington ME, Roberts RK, Mullen MD (2001) Nitrogen fertilization of notill cotton on loess-derived soils. Agronomy Journal 93: 157-163.doi:10.2134/agronj2001.931157x

Hussain SZ, Faird S, Anwar M, Gill MI, Baugh MD (2000) Effect of plant density and nitrogen on the yield of seed cotton-variety CIM-443. Sarhad Journal of Agriculture 16: 143-147.

Hutmacher RB, Travis RL, Rains DW, Vargas RN, Roberts BA, Weir BL, Wright SD, Munk DS, Marsh BH, Keeley, MP, Fritschi FB, Munier DJ, Nichols RL, Delgado R (2004) Response of recent Acala cotton cultivars to variable nitrogen rates in the San Joaquin Valley of California. Agronomy Journal 96: 48-62. doi: 10.2134/agronj2004.0048

Khader SESA, Prakash AH (2007) Nutritional and physiological disorders of cotton. Model Training Course on "Cultivation of Long Staple Cotton (ELS)" December 15-22, 2007, Central Institute for Cotton Research, Regional Station, Coimbatore.

LaFerney PE (1969) Cotton quality, price, and use value: A statistical model of a textile processing plant. Journal of Agricultural and Applied Economics 1 : 91-97. doi: https://doi.org/10.1017/S0081305200024316.

MacDonald S, Naik G, Landes R (2010) Markets, institutions, and the quality of agricultural products: cotton quality in India. Agricultural & Applied Economics Association 2010 AAEA,CAES, & WAEA Joint Annual Meeting, Denver, Colorado, July 25-27, 2010. doi: 10.2139/ssrn.2124395

Makhdum MI, Malik MNA, Chaudhry FI, Shabab-Ud-Din C (2001) Effect of gypsum as a sulphur fertilizer in cotton production. International Journal of Agricultural And Biological Sciences 3: 298–300.

Mangal P (2000) Effect of nitrogen, phosphorus and sulphur on yield and quality of cotton and their residual effect on succeeding wheat. Fertiliser news 45: 63-64.

Morrow MR, Krieg DR (1990) Cotton management strategies for a short growing season environment: water-nitrogen considerations. Agronomy Journal 82:52-56. doi:10.2134/agronj1990.00021962008200010011x

Mullins GL, Burmester CH (1990) Dry matter, nitrogen, phosphorus and potassium accumulation by four cotton cultivars. Agronomy Journal 82 : 729-736.doi:10.2134/agronj1990.00021962008200040017x.

Nawaz M, Malik MNA, Chaudhry FI, Makhdum MI (1996) Investigation on phosphorus availability and seed cotton yield in silt loam soils. Journal of Animal and Plant Sciences 6 : 21-23.

Phipps BJ, Stevens WE, Mobley JB, Ward JN (1996) Effect of nitrogen level and mepiquat chloride (Pix) upon maturity. In: Proceeding of Beltwide Cotton Conference held on 9-12 January 1996; Nashville, TN, USA. National. Cotton Counciles America, Memphis, TN. pp. 1211-1212.

Rashidi M, Gholami M (2011) Nitrogen and boron effects on yield and quality of cotton (G. hirsutum L.). International Research Journal of Agricultural Science and Soil Science 1: 118-125.

Read JJ, Reddy KR, Jenkins JN (2006) Yield and fiber quality of Upland cotton as influenced by nitrogen and potassium nutrition. European Journal of Agronomy 24: 282-290. doi:10.1016/j.eja.2005.10.004

Reddy KR, Koti S, Davidonis GH, Reddy VR (2004) Interactive effects of carbon dioxide and nitrogen nutrition on cotton growth, development, yield, and fiber quality. Agronomy. Journal 96: 1148-1157. doi:10.2134/agronj2004.1148.

Rochester IJ, Peoples MB , Constable GA (2001) Estimation of the N fertilizer requirement of cotton grown after legume crops. Field Crops Research 70: 43-53.doi:: 10.1016/S0378-4290(00)00150-7

Rochester IJ, Constable GA, Oosterhuis DM, Errington M (2012) Nutritional Requirements of Cotton during Flowering and Fruiting. In: Oosterhuis DM, Cothren JT (Eds.) Flowering and Fruiting in cotton. The Cotton Foundation Reference Book Series. The Cotton Foundation Cordova, Tennessee, U.S.A. pp. 35-51.

Saleem M, Bilal M, Awais M, Shahid M, Anjum S (2010) Effect of nitrogen on seed cotton yield and fiber qualities of cotton (Gossypium hirsutum L.) cultivars. Journal of Animal and Plant Sciences 20 :23-27.

Scherer HW (2001) Sulphur in crop production-Invited paper. European Journal of Agronomy 14:81-111. http://dx.doi.org/10.1016/S1161-0301(00)00082-4

Seagull RW, Oliveri V, Murphy K, Binder A, Kothari S (2000) Cotton fiber growth and development 2. Changes in cell wall diameter and wall birefringence. Journal of Cotton Science 4: 97-104.

Seilsepour M, Rashidi M (2011) Effect of different application rates of nitrogen on yieldand quality of cotton (G. hirsutum). American-Eurasian Journal of Agricultural & Environmental Sciences 10: 366-370.

Sharma TC, Sharma AP, Amarpal AP, Daankhar TS (2000) Response of sulphur and its sources, phosphorus and nitrogen on seed cotton yield and fiber quality in American cotton. Journal Indian Society Cotton Improvement 25 : 33-36.

Stewart S, Yin F, Main C (2011) Cotton response to sulfur applications. UT Crops News. Available on http://news.utcrops.com/2011/10/cotton-response-to-sulfur-applications/, accessed on 17 September 2016.

Tewolde H, Fernandez CJ (1997) Vegetative and reproductive dry weight inhibition in nitrogen and phosphorus deficient Pima cotton. Journal of Plant Nutrition 20:219-232.doi: 10.1080/01904169709365245

Tewolde H, Fernandez CJ (2003) Fiber quality response of Pima cotton to nitrogen and phosphorus deficiency. Journal Plant Nutrition 26: 223-235.doi: 10.1081/PLN-120016506

Tucker MR (1999) Essential plant nutrients: their presence in North Carolina soils and role in plant nutrition. http://worldcat.org/oclc/780091691/viewonline

Yin X, Gwathmey O, Main C, Johnson A (2011) Effects of sulfur application rates and foliar zinc fertilization on cotton lint yields and quality. Agronomy Journal 103:1794-1803. doi:10.2134/agronj2011.0166.